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THE PERSONAL EQUATION IN BREEDING EXPERIMENTS INVOLVING CERTAIN CHARACTERS OF MAIZE.[1]

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In the summer of 1908 some experiments in the cross-breeding of certain types of maize were begun by the writer and his former colleague, Dr. Frank M. Surface. The present paper has to do with a part of the results obtained by crossing a white sweet variety (♂ parent) with a yellow dent variety (♀ parent). Both varieties used were "pure," in the sense that each bred true to the general type to which it belonged. The history of the sweet variety used has been detailed in another place[2] and need not be repeated here. The important thing to be noted at this time is that in its whole history this sweet corn used in the cross breeding experiments had never been known to produce any but *sweet* (sugary) kernels of an exceptional degree of *whiteness*.[3]

The dent corn used in the experiments was also of known history. A discussion of its history, and of the characteristics of the corn has been given elsewhere.[4] The essential point to be noted here is that during a long period of years it has never produced anything except *starchy* kernels of a deep orange *yellow* color when ripe.

[1] Papers from the Biological Laboratory of the Maine Agricultural Experiment Station, No. 29.

[2] Pearl, R., and Surface, F. M., "Experiments in Breeding Sweet Corn," Me. Agr. Expt. Stat. Ann. Report for 1910, pp. 249–307.

[3] A pure chalky white or, put in the other way, the entire absence of yellow color, is an absolute essential of a high grade of corn from the packer's standpoint. The sweet corn here under discussion is regarded by expert packers as an exceptionally fine strain for their purpose.

[4] Pearl, R., "The Mendelian Inheritance of Certain Invisible Chemical Characters in Maize," *Zeitschr. f. Abst.- u. Vererb.-lehre*, Bd. VI., 1911.

The general results which follow the crossing of a yellow dent (♀) with a white sweet (♂) maize are well known. Yellowness of endosperm is dominant over "whiteness" of endosperm, and "starchiness" over "sweetness." Consequently the F_1 kernels are externally indistinguishable (in fact as well as in theory) from those of the pure yellow dent parent. These F_1 kernels planted give rise to plants bearing ears of which each should have four distinct kinds of F_2 kernels which ought, by theory, to occur in the simple dihybrid ratio, 9 yellow dent, 3 white dent, 3 yellow sweet, 1 white sweet.

The present experiments[1] entirely confirm in all essential respects this general Mendelian result. Certain novel points arose, however, in the course of the work, which led to the present investigation. These points may now be considered.

A large quantity of ears bearing F_2 kernels was raised. These ears were well matured. This was indicated both by their appearance and by the way the seed from them germinated. One of the assistants in the laboratory, Miss Maynie R. Curtis, undertook the sorting and counting of these F_2 kernels on an extensive scale. In this work the following situation immediately developed and was called to the writer's attention. While *in general* the F_2 kernels fell without any doubt or difficulty into the four classes or categories, yellow starchy, white starchy, yellow sweet and white sweet, yet there were a number of kernels on each ear that were extremely difficult of classification. These kernels were, in short, *intermediate* in respect to their external visible *somatic* characters, and might, in the individual case, be put with equal propriety into either of two classes. Into which class such an intermediate kernel would actually be put plainly depended upon the personal bias of the observer, rather than upon any peculiarity of the kernel itself. This result appeared to be of enough interest and potential significance to warrant a more extended and thorough investigation of the matter. The present paper deals with the results of such a study.

[1] A detailed description of the conditions and manner of these experiments has been given elsewhere (Pearl, *loc. cit.*) and need not be repeated.

Statement of Problems and Plan of Investigation.

The problems with which this work is concerned may be summarily stated as follows:

1. To what extent is the personal equation of the observer a significant factor in the Mendelian ratios described for simple experiments with cross-bred maize? In other words, how closely would the different individuals of a group of competent biological observers agree in their classification and count of the *same* F_2 material from a maize cross involving such relatively simple and easily judged unit characters as color of endosperm, or chemico-physical character of endosperm (starchy or sweet)?

2. Does somatic "intermediateness" in maize imply gametic "intermediateness"? In other words, do F_2 kernels which are intermediate *somatically* give rise to any different sort of progeny when planted than do kernels which belong clearly and indubitably to one or another of the well-defined *gametic* classes in F_2? If they are true "blends" in the Galtonian sense, they would certainly be expected so to do. If, however, they merely represent a phenomenon essentially like the incomplete or partial (somatic) dominance so frequently observed in Mendelian work, it would be expected that their progeny would differ in no essential particular from that obtained from somatically non-intermediate kernels having the same gametic constitution.

To test these questions the following plan was devised: Four ears bearing F_2 kernels were taken quite at random from a lot of about two bushels of such ears, which in turn was a random sample of a whole crop which included a much larger number of bushels. Each of these four ears was given an arbitrary number and was separately shelled, great care being taken to see that no kernels were lost. All the kernels from each ear were preserved together in a bag (or box). The shelling was done in the writer's laboratory in the presence of several workers, so that there can be no question whatsoever, that all of the kernels in each one of the four parcels originally grew upon the same ear.

Three of the ears so dealt with (Nos. 8, 9 and 10) were normal in every respect. Ear No. 11 was slightly abnormal in the respect that a fungus had attacked some of the grains, giving them a slight pinkish tinge in addition to their own proper

color. This was especially noticeable in the case of the "white" sweet grains of the ear, because in a mature, dry sweet corn kernel "white" means merely the absence of any color (yellow or other). The grain is translucent and "not colored." Any extraneous color such as that arising from a fungus attack will be the more evident. The same considerations apply to the white starchy kernels, except that here the starch of the endosperm gives the grain a positive white color.

The kernels from each of the four ears having been separately shelled and preserved as described, fifteen persons (including the writer) were asked to sort the kernels of each ear into the four categories, yellow starchy, white starchy, yellow sweet and white sweet, and then count and record (on blanks provided for the purpose) the number of each sort found. Four small vials containing *typical* kernels of each sort were given to each observer as comparison samples. The only instructions given the observers were:

1. To sort and count the material *independently*.
2. To open and handle only one parcel of seed at a time.
3. Not to lose a kernel.
4. To count correctly, *i. e.*, to make sure that the total numbers of kernels counted tallied with the total numbers in the parcel, which numbers were set down on the blank for each ear.

Especial pains was taken to insure that no observer (with the exception of Nos. VI., VII., VIII. and XI.) should know, in advance of his count, the nature of the experiments which gave origin to the material, or the expected Mendelian ratio between the several classes of kernels. No observer[1] was, of course, allowed to see the results of the counts by others until after his own had been completed. In short every effort was made to insure in all possible ways that the counts tabled should be the unprejudiced, unbiased, independent and purely objective statements of the opinions of a group of competent biological observers as to the proper classification of the F_2 kernels from these four ears of maize.

We may next consider the observers who took part in this work. At the outstart the writer wishes to express his indebted-

[1] With the single exception of No. XI., and in this case it was some *months* later that his own counts were made.

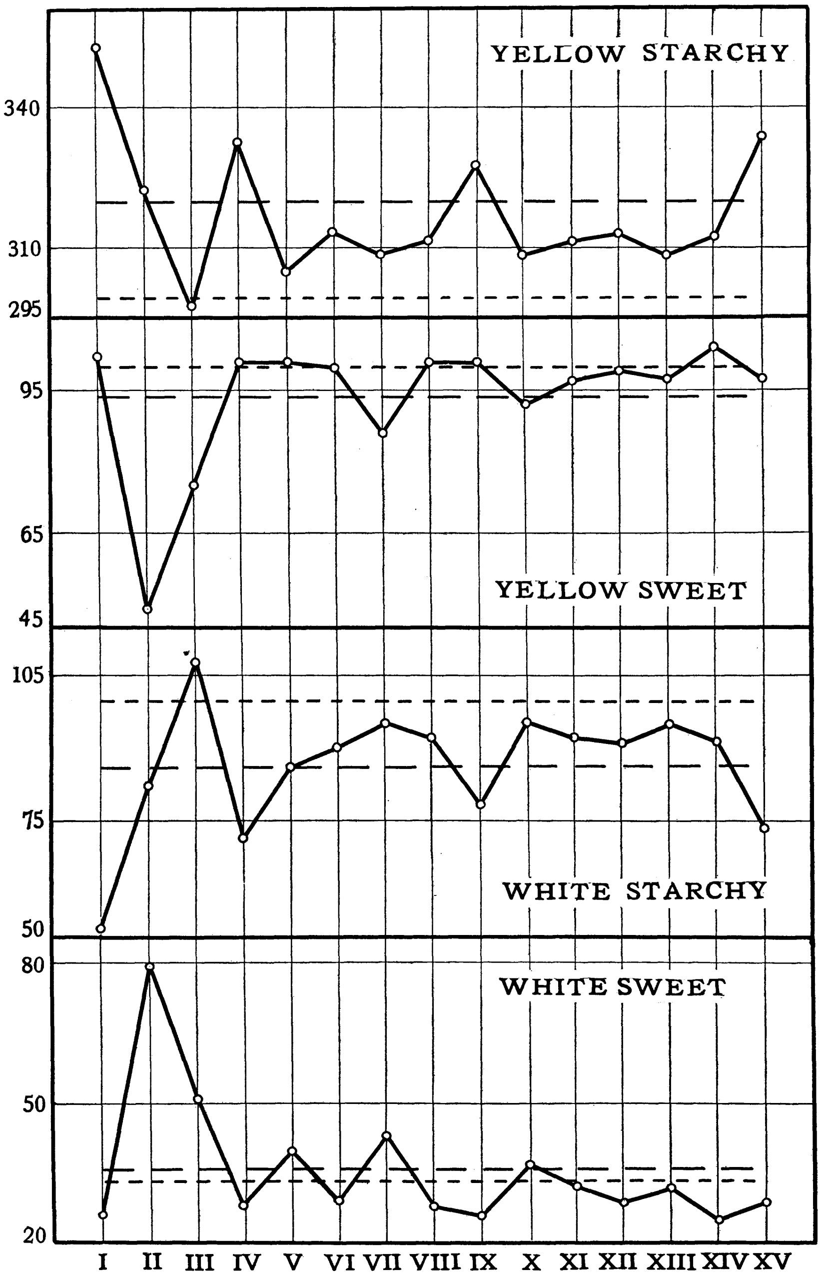

FIG. 1. Diagram showing the count of the different observers of each of the four classes of kernels for ear No. 8.

ness to all of those who coöperated in the investigation, and his appreciation of the painstaking interest and care given to the sorting and counting by all. Table I. gives the name, academic degree and official position of each of the coöperating individuals. For convenience of reference in the paper each observer has been assigned a Roman numeral.

TABLE I.

LIST OF OBSERVERS COÖPERATING IN THE PRESENT STUDY.

No.	Name.	Academic Degree.	Official Position.
I.	W. J. Morse.	M.S.	Plant pathologist, Maine Experiment Station.
II.	C. E. Lewis.	Ph.D.	Associate plant pathologist, Maine Experiment Station.
III.	G. E. Simmons.	M.S.	Professor of agronomy, University of Maine.
IV.	M. E. Sherwin.	M.S.	Assistant professor of agronomy, North Carolina College of Agriculture.
V.	Wallace Craig.	Ph.D.	Professor of philosophy, University of Maine.
VI.	Raymond Pearl.	Ph.D.	Biologist, Maine Experiment Station.
VII.	Frank M. Surface.	Ph.D.	Biologist, Kentucky Experiment Station.[1]
VIII.	Maynie R. Curtis.	M.A.	Assistant in biology, Maine Experiment Station.
IX.	Lottie E. McPheters.	—	Computer, Maine Experiment Station.
X.	Frank Pearl.	—	Farmer and practical corn breeder.
XI.	W. Johannsen.	M.D.	Professor of plant physiology, University of Copenhagen.
XII.	P. Boysen Jensen.	Ph.D.	Instructor in plant physiology, University of Copenhagen.
XIII.	Jenny Hempel.	M.Sc.	Assistant in plant physiology, University of Copenhagen.
XIV.	Gerda Dohlmann.	—	Assistant in plant physiology, University of Copenhagen.
XV.	Gilman A. Drew.	Ph.D.	Professor of Biology, University of Maine.

Certain points regarding this list of coöperators need to be discussed. In the first place it is obvious that any one of them (with the possible exception of X.) might in the ordinary course of his work carry out a Mendelian experiment with maize, either independently or in coöperation with someone else. If this were done and the results published they would certainly be accepted by the biological public as a precise and true statement of the facts regarding the material which was in the experimenter's hands. That is, if any worker in this list published a statement that a Mendelian experiment which he had conducted with

[1] At the time this work was done: Associate Biologist, Maine Experiment Station.

maize led to a ratio of, for example, 759 : 243 : 252 : 90 this statement would not be doubted or questioned.

In the second place it is worth while to consider the training, or lines of work with which these 15 observers have had to do. Of six (Nos. I., II., XI., XII., XIII., XIV.) the training and work has been primarily *botanical*. Four of these (the Danish group,

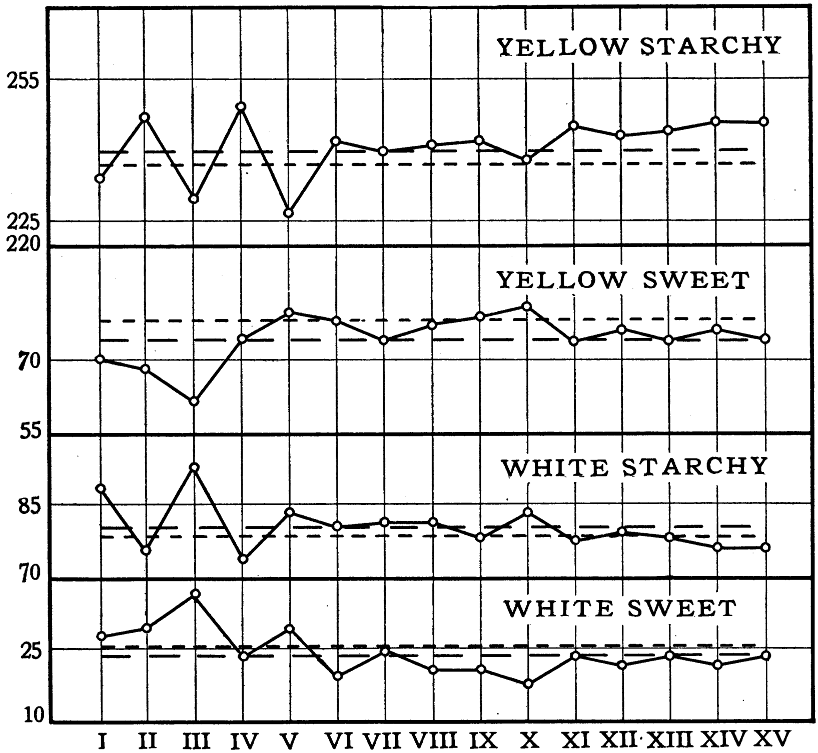

FIG. 2. Diagram showing the count of the different observers of each of the four classes of kernels for ear No. 9.

Nos. XI. to XIV. inclusive) have had particularly to do with the data of experimental plant breeding, in connection with the brilliant and fundamental researches of Professor Johannsen. The training and special field of work of five (Nos. V., VI., VII., VIII. and XV.) of the observers has been *zoölogical*. Of these five three (Nos. VI., VII. and VIII.) have had experience with the data and methods of investigation in experimental breeding.

Table II.

Showing the Classification of the Kernels of Ear No. 8 by the Different Observers.

Observer.	Classes of Kernels.					
	Yellow Starchy.	Yellow Sweet.	White Starchy.	White Sweet.	Total Starchy.	Total Sweet.
Mendelian Expectation.	299.25	99.75	99.75	33.25	399.00	133.00
I.	352	102	52	26	404	128
II.	322	49	82	79	404	128
III.	298	75	108	51	406	126
IV.	332	101	71	28	403	129
V.	305	101	86	40	391	141
VI.	313	100	90	29	403	129
VII.	308	86	95	43	403	129
VIII.	311	101	92	28	403	129
IX.	327	101	78	26	405	127
X.	308	92	95	37	403	129
XI.	311	97	92	32	403	129
XII.	313	99	91	29	404	128
XIII.	308	97	95	32	403	129
XIV.	312	104	91	25	403	129
XV.	333	97	73	29	406	126
Totals.	4,753	1,402	1,291	534	6,044	1,936
Means.	316.87	93.47	86.67	35.60	402.93	129.07

Another of the five (No. V.) adds to the special training of the zoölogist that of the philosopher and psychologist, which by traditional standards, at least, ought to aid in the development of a discriminative judgment. The training of two of the observers (Nos. III. and IV.) has been agricultural. Further, both of these men belong by birth, early life and education to the "corn belt" section of the country, and are thoroughly and intimately familiar with maize. They have had experience in corn judging, which demands the appreciation of very small differences in ear characters. Observer No. X., while not a scientific student of breeding, has had successful practical experience in corn breeding, and is a careful observer. Observer No. IX. has been specially trained in biometric work in the writer's laboratory and has had considerable experience in measuring, sorting small variations out of mixed material, and similar work.

Results.

I.

The results of the counts of the four ears by the different observers are set forth in Tables II. to V. inclusive. Each of

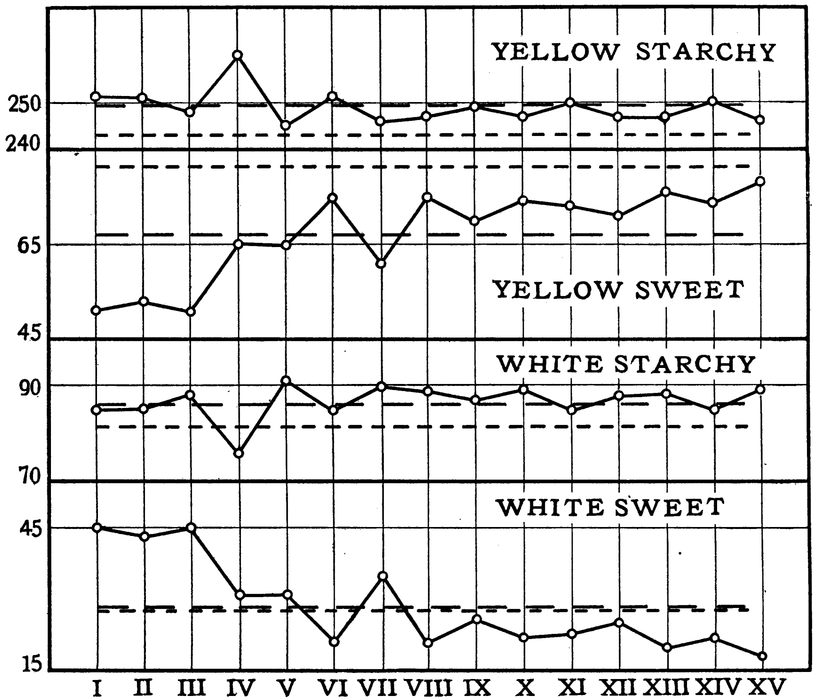

FIG. 3. Diagram showing the count of the different observers of each of the four classes of kernels for ear No. 10.

these tables is arranged as follows: Columns are given for the four different classes of kernels, yellow starchy, yellow sweet, white starchy and white sweet. Also columns are given for total starchy and total sweet. The first row of each table shows the Mendelian expectation for each class. The following lines show the distribution of the kernels as reported by each of the fifteen observers.

The data for the color classes given in these tables are shown graphically in Figs. 1 to 4 inclusive. One of these diagrams is devoted to each of the four ears used in the study. Each figure gives the plotting of each observer's count of the four classes of kernels. The Mendelian expectation is plotted in each case as a dotted straight line and the mean of the results of the different observers as a straight line of dashes.

From these tables and diagrams we note the following points:

TABLE III.

SHOWING THE CLASSIFICATION OF THE KERNELS OF EAR NO. 9 BY THE DIFFERENT OBSERVERS.

Observer.	Classes of Kernels.					
	Yellow Starchy.	Yellow Sweet.	White Starchy.	White Sweet.	Total Starchy.	Total Sweet.
Mendelian Expectation.	237.33	79.11	79.11	26.37	316.44	105.48
I.	234	71	89	28	323	99
II.	247	69	76	30	323	99
III.	230	62	93	37	323	99
IV.	249	75	74	24	323	99
V.	227	81	84	30	311	111
VI.	242	79	81	20	323	99
VII.	240	75	82	25	322	100
VIII.	241	78	82	21	323	99
IX.	242	80	79	21	321	101
X.	238	82	84	18	322	100
XI.	245	75	78	24	323	99
XII.	243	77	80	22	323	99
XIII.	244	75	79	24	323	99
XIV.	246	77	79	22	323	99
XV.	246	75	77	24	323	99
Totals.	3,614	1,131	1,215	370	4,829	1,501
Means.	240.93	75.40	81.00	24.67	321.93	100.07

1. For no one of the ears is there entire agreement among all the observers as to the number of kernels falling in any one of the color classes. There is entire agreement among the observers as to the total number of starchy and sweet kernels in the case of two ears (Nos. 10 and 11), leaving out of account the loss of one starchy kernel from ear No. 10 between the time when this ear was counted by observers X. and XI. In the case of the other two ears (Nos. 8 and 9) there is some disagreement as to the number of starchy and sweet kernels. In no case, however, is the disagreement in regard to these characters so marked as that in respect to color characters.

2. The relative amount of divergence among the observers in regard to the distribution of the kernels in color classes is strikingly different for different ears. Ear No. 9 plainly bore kernels which were relatively easy to classify. The same was true of ear No. 10. On the other hand the kernels of ears 8 and 11 offered many difficulties in classification. But in the case of ear No. 11 the difficulty was largely confined to the sweet kernels, there being close agreement between all the observers but one

TABLE IV.

SHOWING THE CLASSIFICATION OF THE KERNELS OF EAR NO. 10 BY THE DIFFERENT OBSERVERS.

Observer.	Classes of Kernels.					
	Yellow Starchy.	Yellow Sweet.	White Starchy.	White Sweet.	Total Starchy.	Total Sweet.
Mendelian expectation.	243.00	81.00	81.00	27.00	324.00	108.00
I.	251	51	85	45	336	96
II.	251	53	85	43	336	96
III.	248	51	88	45	336	96
IV.	260	65	76	31	336	96
V.	245	65	91	31	336	96
VI.	251	75	85	21	336	96
VII.	246	61	90	35	336	96
VIII.	247	75	89	21	336	96
IX.	249	70	87	26	336	96
X.[1]	247	74	89	22	336	96
XI.[1]	250	73	85	23	335	96
XII.[1]	247	71	88	25	335	96
XIII.[1]	247	76	88	20	335	96
XIV.[1]	250	74	85	22	335	96
XV.[1]	246	78	89	18	335	96
Totals.	3,775	1,012	1,300	428	5,035	1,440
Means.	249.00	67.47	86.67	28.53	335.67	96.00

(No. 1) with regard to the yellow and white starchy kernels of this ear.

3. The cause of the discrepancies between the counts of the several observers is obvious from the data. It will be seen at a glance from the diagrams that generally when an observer's count of the *yellow* starchy kernels of an ear, for example, deviated from the mean in excess, this same observer's count of the *white* starchy kernels deviated from the mean in defect, and by an amount approximately corresponding to the positive deviation in the other case. In other words, certain kernels, either starchy or sweet, which were called "yellow" by one observer were called "white" by another. This brings out in a striking way what was obvious to each observer who handled this maize, namely, that there were on each ear a number of both starchy and sweet kernels which were intermediate in respect to color. The distribution of such kernels into the Mendelian categories depends upon the

[1] Between the time when ear No. 10 was counted by observer X. and observer XI. one starchy kernel was lost. Consequently the totals on this ear (sum of all starchy and all sweet kernels) are smaller by one for observers XI. to XV. inclusive than for the other observers.

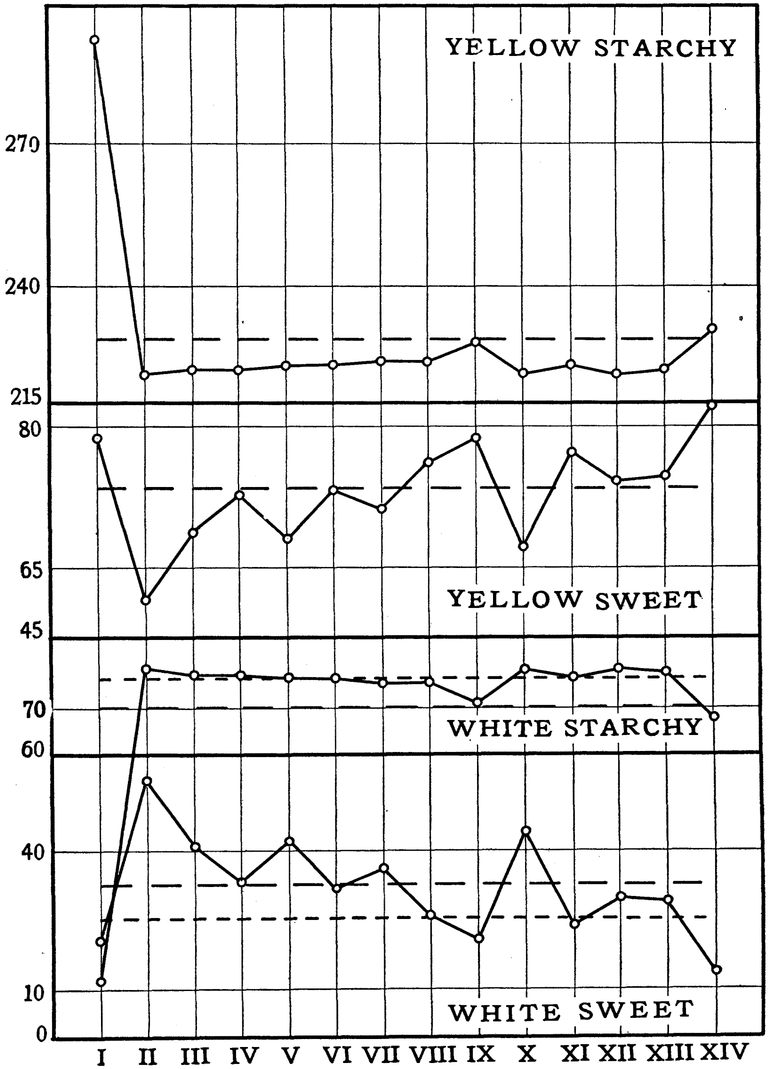

FIG. 4. Diagram showing the count of the different observers of each of the four classes of kernels for ear No. 11.

personal "equation" or bias of each individual observer. As a matter of fact it was possible (and this was done) to make a perfectly graded series of either starchy or sweet kernels from a single ear which ranged from pure white at one end to pure deep

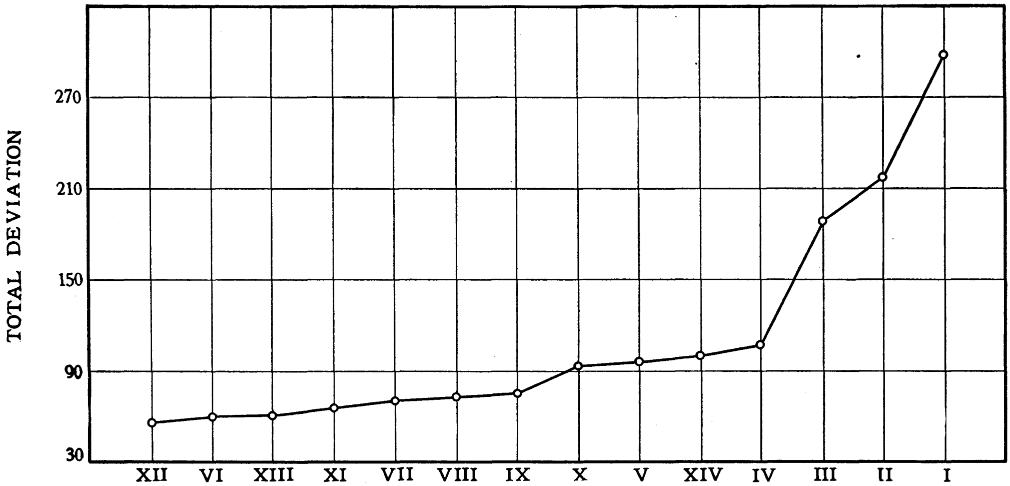

FIG. 5. Diagram showing the total deviations in all the counts of all observers.

TABLE V.

SHOWING THE CLASSIFICATION OF THE KERNELS OF EAR NO. 11 BY THE DIFFERENT OBSERVERS.

Observer.	Classes of Kernels.					
	Yellow Starchy	Yellow Sweet.	White Starchy.	White Sweet.	Total Starchy.	Total Sweet.
Mendelian Expectation.	228.87	76.29	76.29	25.43	305.16	101.72
I.	292	87	7	21	299	108
II.	221	53	78	55	299	108
III.	222	67	77	41	299	108
IV.	222	75	77	33	299	108
V.	223	66	76	42	299	108
VI.	223	76	76	32	299	108
VII.	224	72	75	36	299	108
VIII.	224	82	75	26	299	108
IX.	228	87	71	21	299	108
X.	221	64	78	44	299	108
XI.	223	84	76	24	299	108
XII.	221	78	78	30	299	108
XIII.	222	79	77	29	299	108
XIV.[1]	231	94	68	14	299	108
Totals.	3,197	1,064	989	448	4,186	1,512
Means.	228.36	76.00	70.64	32.00	299.00	108.00

[1] No count of this ear by observer No. XV. is included in this table.

yellow at the other end, with each intermediate step practically as small as one cared to make it. An attempt was made to obtain photographs of such series of kernels which would demonstrate the fact of this gradation pictorially, but the photographic resources at command were not equal to the task and it had to be abandoned.

4. The data presented fully demonstrate, I think, the interesting fact that if each of these fifteen competent, and with one exception (No. X.), specially trained observers had independently undertaken an investigation of Mendelian inheritance in maize, and all used the same seed, of at least the two strains here employed, grown their crops in the same place, and even studied *identically the same* progeny ears, *no two would have fully agreed in the numerical values of the F_2 ratios.*

II.

Let us now consider the question as to whether these deviations due to personal equation are of sufficient magnitude to be practically significant. The whole of the remainder of this paper will be devoted to a discussion, from different standpoints, of the quantitative aspects of the recorded classifications of the several observers. All these data will bear upon this general point. To answer the question specifically raised in this section it will only be necessary to show the range of the variation exhibited in the counts made. Table VI. gives for the four ears and the four classes of kernels on each ear (*a*) the mean numbers of kernels found by averaging the counts of all observers, (*b*) the minimum and the maximum recorded number of kernels, (*c*) the total range of variation shown in the records, and (*d*) the percentage which this range is of the mean of the same class.

It is evident from this table that the personal element is one of real significance. When two careful observers can differ in their count of the same set of objects by as much as one and a half times the actual number of the objects counted the factor which leads to this difference is certainly not to be neglected.

An examination of the standard deviations and coefficients of variation of the counts leads to the same result. These constants are shown in Table VII. It should be said in this

TABLE VI.

SHOWING THE RANGE OF VARIATION EXHIBITED BY ALL OBSERVERS IN THE SEVERAL CLASSIFICATIONS.

Ear No.	Class.	Mean.	Lowest Count.	Highest Count.	Range.	Percentage of Range in Mean.
8	Yellow starchy.	316.87	298	352	54	17.0
8	Yellow sweet.	93.47	49	104	55	58.8
8	White starchy.	86.67	52	108	56	64.6
8	White sweet.	35.60	25	79	54	151.7
9	Yellow starchy.	240.93	227	249	22	9.1
9	Yellow sweet.	75.40	62	82	20	26.5
9	White starchy.	81.00	74	93	19	23.4
9	White sweet.	24.67	18	37	19	77.0
10	Yellow starchy.	249.00	245	260	15	6.0
10	Yellow sweet.	67.47	51	78	27	40.0
10	White starchy.	86.67	76	91	15	17.3
10	White sweet.	28.53	18	45	27	94.6
11	Yellow starchy.	228.36	221	292	71	31.1
11	Yellow sweet.	76.00	53	94	41	53.9
11	White starchy.	70.64	7	78	71	100.5
11	White sweet.	32.00	14	55	41	128.1
Mean.						56.2

connection that for the particular sort of problem here dealt with it would appear that the method of expressing the degree of variability which is used in Table VI. (*i. e.*, the absolute value of the range and its relation to the mean) is probably of more real value than are the conventional constants given in Table VII. In the present instance it is the *range* of variation (*i. e.*, the extreme amounts by which different observers differ in their counts) which is the thing of primary interest and practical significance.

Table VII. gives the standard deviation and coefficient of variation for the counts of each class of kernels.

TABLE VII.

SHOWING THE ABSOLUTE AND RELATIVE VARIATION IN THE COUNTS OF THE SEVERAL CLASSES OF KERNELS.[1]

Ear.	Yellow Starchy.		White Starchy.		Yellow Sweet.		White Sweet.	
	Standard Deviation.	Coeff. of Var.	Standard Deviation.	Coeff. of Var.	Standard Deviation.	Coeff. of Var.	Standard Deviation	Coeff. of Var.
8	13.44	4.24	12.90	14.98	13.85	14.82	13.58	38.14
9	6.09	2.53	4.84	5.98	4.91	6.51	4.69	19.00
10	3.52	1.41	3.46	3.99	9.08	13.46	9.08	31.84
11	17.86	7.82	17.86	25.28	10.52	13.84	10.52	32.88

[1] Since these constants are not used in any detailed comparisons it has not been thought necessary to calculate probable errors. All the necessary data are at hand, however, if anyone wishes to make these computations. It need only be remembered that for ears 8, 9 and 10, $n = 15$, and for ear 11, $n = 14$.

This table brings out several points which need discussion. These are:

1. The amount of variation, both absolute and relative, in the counts is shown by the measures here used to be very large for some ears and classes of kernels. For no ear, taken as a whole, can the variation fairly be considered negligible. Thus the conclusion previously reached by another method is confirmed.

2. The amount of variation in the sorting and counting is distinctly different for the different ears. From the values of the constants it would appear that ear No. 11 presented the greatest difficulty in respect to the classification of starchy kernels. In respect to sweet kernels ears No. 8 takes rank as offering the greatest difficulties. The starchy kernels of ear No. 10 were the easiest to classify of all starchy kernels. In the case of sweet kernels ear No. 9 had fewer intermediates (*i. e.*, was easier to classify) than any other ear.

3. *Relatively* there was closest agreement among the observers in respect to yellow starchy kernels, and least agreement in respect to white sweet kernels. This table illustrates the fact which was evident to the observers themselves, that there were marked differences in the ease with which the kernels of different ears and different classes could be sorted.

Now while it has been shown that the fifteen observers do not agree in their classification and counts, and that the differences are too large to be neglected, it may fairly be asked if the same result would appear if the group of observers participating were not merely scientifically trained and familiar with maize, but in addition had had a considerable amount of actual experience in the detailed study of variation and inheritance in plants. In other words, is not that special familiarity with the object which comes with the active prosecution of research in a particular field worth something in reducing the magnitude of one's personal error or "equation"? To get some light on this point Table VIII. has been prepared. This is made up in exactly the same way as Table VI., *except* that only observers VI., VII., VIII., IX., XI., XII., XIII. and XIV. are included. These eight observers, comprising the staffs of Professor Johannsen's and the writer's

laboratories, have certainly had more extended experience in the direct and immediate study of plant breeding and of variation in plants (involved in all breeding investigation) than have the other observers of the original fifteen. Lists of published papers could be cited in proof of this were it necessary, but the fact is obvious. Will this group of workers on problems of variation and inheritance show a similar degree of variability in their counts to that brought out in Table VI.?

Table VIII.

Showing the Range of Variation Exhibited by Observers VI. to IX. Inclusive, and XI. to XIV. Inclusive.

Ear No.	Class.	Mean.	Lowest Count.	Highest Count.	Range.	Percentage of Range in Mean.
8	Yellow starchy.	312.88	308	328	20	6.4
8	Yellow sweet.	98.13	86	104	18	18.3
8	White starchy.	90.50	78	95	17	18.8
8	White sweet.	30.50	25	43	18	59.0
9	Yellow starchy.	242.88	240	246	6	2.4
9	Yellow sweet.	77.00	75	80	5	6.5
9	White starchy.	79.75	77	82	5	6.3
9	White sweet.	22.38	21	25	4	17.9
10	Yellow starchy.	248.38	246	251	5	2.0
10	Yellow sweet.	71.88	61	76	15	20.9
10	White starchy.	87.13	85	90	5	5.7
10	White sweet.	24.13	20	35	15	62.2
11	Yellow starchy.	224.50	221	228	7	3.1
11	Yellow sweet.	81.50	72	87	15	18.4
11	White starchy.	74.50	71	78	7	9.4
11	White sweet.	26.50	21	36	15	56.6
Mean.						19.6

It is seen from comparison of this table with Table VI. that the amount of variation in the sorting and counting is distinctly reduced in the group of students of variation. Whereas the average percentage of range in mean is 56.2 for Table VI., it is but 19.6, or only approximately *one third* as much, for Table VIII. Thus it appears that in this case, just as would be expected on general grounds, special experience or practice in a particular line greatly reduces the personal equation. It must be said, however, that even with the group of observers included in Table VIII., the differences are too large to be neglected. When the range of variation amongst different observers of the same thing amounts on the average to approxi-

mately one fifth (19.6 per cent.) of the mean value of the thing counted it indicates a source of error not lightly to be dismissed.

III.

It is desirable next to examine somewhat more closely into the nature and distribution of the discrepancies among the observers. A point of particular interest is to determine to what extent the counts indicate a definite and persistent bias on the part of an observer. There may be great variation in the counts of several observers of the same set of things and yet each observer's judgments may be distributed quite at random about the mean. In order to get more light on this and some other matters Table IX. has been prepared. This table gives in successive columns for the four kernel classes, first, the mean deviation from the mean, all deviations being taken together without reference to sign (*i. e.*, the mean total deviation), and second, the mean net deviation from the mean, got by taking the algebraic sum of the deviations. All four ears are used in getting these mean deviations. An example will make clear the method of obtaining the values given in this table. An examination of Tables II. to V. inclusive shows the following set of deviations from the means in the counts of yellow sweet kernels by observer No. V.

+ Deviations from Mean.	— Deviations from Mean.
7.53 (ear 8)	2.47 (ear 10)
5.60 (ear 9)	10.00 (ear 11)
13.13 = sum of + deviations	12.47 = sum of − deviations.

$$\frac{13.13 + 12.47}{4} = 6.40 = \text{mean } \textit{total} \text{ deviation from mean.}$$

$$\frac{13.13 - 12.47}{4} = +0.165 = \text{mean } \textit{net} \text{ deviation from mean.}$$

The last column of the table gives the total deviation from the mean of each observer, all ears being taken together and the deviations summed without regard to sign.

It is strikingly evident from the mean net deviations in this table that each observer was "a law unto himself." Nearly every one of the fifteen evidently had a different system of sorting.

TABLE IX.

SHOWING THE MEAN DEVIATION FROM THE MEAN (TOTAL AND NET) AND TOTAL DEVIATIONS OF THE COUNTS OF ALL OBSERVERS.

Observer.	Yellow Starchy.		Yellow Sweet.		White Starchy.		White Sweet.		Total Deviation on All Ears and All Classes.
	Mean Total Deviation from Mean.	Mean Net Deviation from Mean.	Mean Total Deviation from Mean.	Mean Net Deviation from Mean.	Mean Total Deviation from Mean.	Mean Net Deviation from Mean.	Mean Total Deviation from Mean.	Mean Net Deviation from Mean.	
I.	26.93	+23.46	10.10	− 0.34	26.995	−22.995	10.44	+ 0.14	297.82
II.	6.04	+ 2.36	22.09	−22.09	4.68	+ 1.84	21.55	+21.55	217.40
III.	9.29	− 9.29	14.34	−14.34	10.26	+10.26	13.30	+13.30	188.72
IV.	11.04	+ 7.86	2.86	+ 0.93	9.93	− 6.75	2.94	− 1.20	107.04
V.	8.79	− 8.79	6.40	+ 0.17	3.34	+ 3.00	5.55	+ 5.55	96.32
VI.	3.54	− 1.08	4.42	+ 4.42	2.59	+ 1.76	4.70	− 4.70	60.98
VII.	4.04	− 4.04	4.59	− 4.59	4.26	+ 4.26	4.55	+ 4.55	70.72
VIII.	3.08	− 3.04	5.92	+ 5.92	3.26	+ 3.26	6.20	− 6.20	73.78
IX.	2.89	+ 2.71	6.42	+ 6.42	2.84	− 2.49	6.70	− 6.70	75.38
X.	4.83	− 4.29	6.65	− 0.085	5.26	+ 5.26	6.65	− 0.05	93.52
XI.	4.08	− 1.54	4.37	+ 4.17	3.84	+ 1.51	4.45	− 4.45	66.92
XII.	3.83	− 2.79	3.17	+ 3.17	3.51	+ 3.01	3.70	− 3.70	56.87
XIII.	5.08	+ 0.77	1.87	+ 1.67	4.51	+ 3.51	3.95	− 3.95	61.58
XIV.	3.40	+ 0.96	9.17	+ 9.17	3.16	− 0.25	9.45	− 9.45	100.68
XV.[1]	8.07	+ 6.07	4.82	+ 4.55	6.67	− 5.11	5.93	− 5.93	76.46

[1] On three ears only.

Some of these differences are very interesting. For example: No. I. had a high net deviation on starchy kernels, tending to overestimate the yellows and practically zero net deviation on sweet kernels; XIV. is exactly the opposite, having very small net deviations on the starchy and tending strongly to overestimate the yellows among the sweet kernels. No. II. had the tendency to underestimate the yellow sweets, and correspondingly to overestimate the white sweets. No. III. consistently underestimated rather heavily all yellows and overestimated all whites. No. IV. did precisely the opposite. No. V. shows a very erratic set of net distributions, owing to his idiosyncrasy respecting the discrimination between starchiness and non-starchiness. The result is that while he underestimated the yellow starchy kernels, he overestimated all the other classes. No. VI. somewhat underestimated the yellow starchy, but overestimated the yellow sweet. No. X. shows an extraordinarily small net deviation on the sweet kernels, but distinctly underestimated the yellow starchy. In general the table shows in a striking way, that the individuality of the observer is a factor to be reckoned with in work of this sort.

It is of some interest to examine the trend of the total deviations given in the last column. The data are shown graphically in Fig. 5, arranged in order from the smallest to the greatest deviation.

This diagram illustrates a point frequently overlooked. It is commonly argued that the more independent judgments one obtains regarding any point the more accurate will the average result be. We are apt to say that if ten men measure a stick the average of their measurements will necessarily be nearer to the true dimension than if but three men measure and their average be taken. But it is plainly evident from Fig. 5 and Tables VI. and VIII. that the inclusion of observers I., II., III. added nothing to the accuracy of the mean. The point which is forgotten in assuming that greater numbers necessarily mean greater accuracy is apparent if we examine the equation for the probable error of a mean which is

$$P.E._M = .67449 \frac{\sigma}{\sqrt{n}}.$$

The probable error, to be sure, varies inversely with n, but it also varies directly with σ, the standard deviation. And, what is here of primary importance, the standard deviation tends to increase as n increases. Whether the probable error shall be smaller or not as the number of observations is increased depends upon what has happened in the meantime to the standard deviation. When n is small, as in the case here under discussion, the effect on the standard deviation of taking $n + 1$ observations as compared with n may greatly outweigh its effect in the denominator of the probable error fraction.

IV.

The next point to be considered is the relative constancy of the same observer's error. If each of the fifteen observers had made a second count of all the ears at some considerable interval of time after the first, how closely would the recounts tally with the original counts? Such an experiment really tests, of course, the stability or constancy of an observer's judgment. It indicates the degree to which his standard of sorting is absolute, and to what extent it fluctuates.

It was not feasible to ask all of the original fifteen observers to go to the labor of recounting these ears. Second counts made after a relatively long lapse of time are, however, available from three observers (namely, VI., VIII. and IX.) for all four ears. While this gives only comparatively meager data, still some points of interest appear. These data are given in Tables X., XI. and XII. It should be said that the recounting was done in the same way as the original count. In each case the observer had no access to the original data while the second count was in progress. No one of the three had any remembrance of what his (or her) original counts were. The writer has not been able to discover any factor which would make these recounts anything other than what they were intended to be, namely, really independent determinations of the same material by the same observers after a long lapse of time.

It will be remembered (*cf.* p. 349 *supra*) that one kernel from ear No. 10 was lost in the course of the original counting. It is therefore obvious that all the recounts of this ear must of necessity be one kernel smaller than the first counts.

Table X.

Original and Second Counts of Ears 8 to 11 by Observer No. VI.

Ear and Count.	Classes of Kernels.				Date.
	Yellow Starchy.	Yellow Sweet.	White Starchy.	White Sweet.	
8, Original.	313	100	90	29	January 21, 1910.
8, Recount.	312	100	91	29	August 10, 1911.
Difference.	−1	0	+1	0	
9, Original.	242	79	81	20	January 21, 1910.
9, Recount.	240	76	83	23	August 11, 1911.
Difference.	−2	−3	+2	+3	
10, Original.	251	75	85	21	January 21, 1910.
10, Recount.	244	73	91	23	August 11, 1911.
Difference.	−7	−2	+6	+2	
11, Original.	223	76	76	32	January 21, 1910.
11, Recount.	223	75	76	33	August 10, 1911.
Difference.	0	−1	0	+1	

The data in these tables indicate that, so far at least as these three observers are concerned, the judgment of the individual is reasonably constant. This is plain if the total deviation of

Table XI.

Original and Second Counts of Ears 8 to 11 by Observer No. VIII.

Ear and Count.	Classes of Kernels.				Date.
	Yellow Starchy.	Yellow Sweet.	White Starchy.	White Sweet.	
8, Original.	311	101	92	28	January 20,1910.
8, Recount.	309	93	94	36	August 12, 1911.
Difference.	−2	−8	+2	+8	
9, Original.	241	78	82	21	January 20, 1910.
9, Recount.	243	79	80	20	August 12, 1911.
Difference.	+2	+1	−2	−1	
10, Original.	247	75	89	21	January 20, 1910.
10, Recount.	246	73	89	23	August 12, 1911.
Difference.	−1	−2	0	+2	
11, Original.	224	82	75	26	January 20, 1910.
11, Recount.	223	81	76	27	August 12, 1911.
Difference.	−1	−1	+1	+1	

Table XII.

Original and Second Counts of Ears 8 to 11 by Observer No. IX.

Ear and Count.	Classes of Kernels.				Date.
	Yellow Starchy.	Yellow Sweet.	White Starchy.	White Sweet.	
8, Original.	327	101	78	26	January 21, 1910.
8, Recount.	314	98	89	31	August 11, 1911.
Difference.	−13	−3	+11	+5	
9, Original.	242	80	79	21	January 21, 1910.
9, Recount.	240	76	83	23	August 11, 1911.
Difference.	−2	−4	+4	+2	
10, Original.	249	70	87	26	January 21, 1910.
10, Recount.	246	71	89	25	August 11, 1911.
Difference.	−3	+1	+2	−1	
11, Original.	228	87	71	21	January 21, 1910.
11, Recount.	222	88	77	20	August 12, 1911.
Difference.	−6	+1	+6	−1	

recounts from original counts be considered. In the case of observer No. VI. a total of sixteen kernels were differently classified in the recount from what they were originally. Since the whole number of kernels involved in the experiment was 1,792, this means a discrepancy of less than one per cent. between two independent sortings more than a year apart. Such an error is

certainly negligible. Observer No. VIII. classified eighteen kernels, all told, differently in the recount than in the original. This again is only about one per cent. of the total kernels handled, and cannot be regarded as a significant error. In both of these cases (VI. and VIII.) the discrepancies had to do entirely with the color classification. With observer IX. this was not the case. On both ear 8 and ear 9 she classed two kernels as sweet in the recount which she had originally called starchy. Altogether this observer classified thirty-five kernels differently in the recount from what she did in the original. This however represents a relative error of a little less than two per cent. No very great stress could be laid upon such an error.

From the tables it will be noted that there was a marked and nearly uniform tendency on the part of all three observers to underestimate the yellows (both starchy and sweet) and to overestimate the whites, in the recounts as compared with the originals. It seems probable that the cause of this lies, in part at least, in a fading of the yellow color during the time since the first counts were made. Thus it may be that kernels which were plainly yellow when first counted are now white or very nearly so. A further fact which would indicate that fading had occurred is found in the mental impressions of the observers. All three found the material distinctly more difficult to classify when recounted than when originally counted. One feels certain that a part, at least, of this is due to a change in the material itself.

Recognizing fully the meagerness of the material, the facts so far as they go seem to indicate clearly that the same observer is likely to classify the same material in about the same way every time. If a particular kind of bias is shown in one count it will appear essentially unaltered in successive trials. This is probably more true of observers especially experienced in dealing with the data of variation than in the case of those without such experience, though figures are lacking to demonstrate this.

V.

We come next to the consideration of the second question proposed at the beginning (p. 341). This was: "Does somatic 'intermediateness' in maize imply gametic 'intermediateness'? In

other words, do F_2 kernels which are intermediate *somatically* give rise to any different sort of progeny when planted than do kernels which belong clearly and indubitably to one or another of the well defined gametic classes in F_2?" To answer this question carefully controlled plantings of somatically intermediate kernels were made in 1910. Series of starchy and of sweet kernels were formed ranging in each case from pure white at one end to pure deep yellow at the other end. Then rows were planted as follows: (1) pure white, (2) deep yellow, (3) the lightest yellow to be found (= somatic intermediates), (4) the yellowest whites to be found (= somatic intermediates). The kernels in classes (3) and (4) were such as would be classified with the yellows by some observers and with the whites by others. The rows included about twenty plants each and were made in duplicate, and in some instances triplicate for both starchy and sweet series. In each row a varying number of ears were self-fertilized (*i. e.*, pollinated by hand with pollen borne on the same plant). Owing to the numerous vicissitudes incident to hand-pollination, together with pressure of other work, as large a number of good ears as would be desirable was not obtained. Some of the possible gametic combinations were not represented at all in the progeny ears. This part of the investigation is, in consequence, not complete. It seems desirable, however, to present briefly the general result shown by the fifty odd ears at hand.

This result was that there was no discernible difference whatever between the progeny of groups (1) and (2) *as a class*, and that of groups (3) and (4) *as a class*. In (3) and (4) some of the kernels planted were of course heterozygotes and some were homozygotes. The same was true, however, of the kernels of (1) and (2). In each case a typical Mendelian result was obtained, and this result could have been predicted in every case (with the exception to be noted presently) had the *gametic* constitution of the kernel been known when it was planted. It could not have been predicted from the *somatic* appearance of the kernel.

The only behavior of an exceptional character observed in these selfed ears was that in certain of the white sweet kernels,

which were homozygous recessives in respect to absence of yellowness and starchiness, selfing brought out a latent red.[1] The three ears of this type which were obtained all came from kernels classified in the planting as pure white (group (1)). No such ears were obtained from selfed sweet kernels in group (4). The total number of homozygous, non-yellow sweet ears obtained was too small, however, to make it at all certain that similar red ears might not, with larger numbers, be obtained from group (4) kernels.

It is planned to get further data on this portion of the investigation, using for planting the kernels of ears 8, 9, 10 and 11 which formed the material for the personal equation part of the work. It can be said at this time that the experiments with cross-bred maize so far conducted furnish no evidence that somatic "intermediateness" connotes gametic intermediateness. The progeny of a deep yellow kernel selfed is not visibly different from that of a light yellow kernel selfed, provided both are of the same gametic constitution. The result of this experiment precisely agrees with Darbishire's[2] extensive study of essentially the same problem with peas. Indeed his final conclusion (*loc. cit.*, p. 71) applies here without change of wording: "That in the attempt to predict the result of a given mating the somatic character not only of the parents and of the ancestors of the individuals mated, but of the individuals themselves, may be entirely left out of account; and that the expectation based on a theory of the contents of the germ cells of the two individuals is fulfilled.

Discussion and Summary.

Results such as are set forth in this paper would certainly have been at one time proclaimed by some as furnishing a refutation of Mendelism. In fact one of the earliest criticisms[3] of Mendelian work was mainly devoted to calling attention to the existence of such somatic intermediates between Mendelian categories in the

[1] A similar result has recently been described by Emerson, R. A. Rept. Amer. Breeders' Assoc., VI., 233–237, 1911.

[2] Darbishire, A. D., "An Experimental Estimation of the Theory of Ancestral Contributions in Heredity." *Proc. Roy. Soc.*, B, Vol. 81, pp. 61–79, 1909.

[3] Weldon, W. F. R., "Mendel's Laws of Alternative Inheritance in Peas." *Biometrika*, Vol. I., pp. 228–254, Plates I. and II., 1902.

case of peas as are here shown to exist in maize. That such variation, provided it be really somatic or fluctuational, is, however, of no real importance in relation to the cardinal facts of Mendelian inheritance has been shown by all experimentalists who have devoted attention to the matter. Bateson[1] (*loc. cit.*, pp. 240–244) gives an illuminating discussion of the whole matter, with special reference to the phenomena in peas. East and Hayes[2] discuss the same point with reference to maize and show that somatic intermediates behave in inheritance in accord with their gametic constitution rather than their somatic appearance. Certainly the time is past when facts such as are set forth in the present paper can be adduced in criticism of basic Mendelian principles.

The essential point brought out by this study is, it seems to me, that the well known *general* fact that every datum of science is a function (in the mathematical sense) of two variables, namely, the observer and the thing observed, is once more emphasized by a particular case.

A thorough investigation which brings out essentially this same point, though conducted on a different class of material and with a somewhat different object in view, has been made by Yule.[3]

It will be freely admitted by everyone as an abstract proposition that the personal idiosyncracy of the observer constitutes a source of error in all scientific observing. Yet how often does the biologist not working on strictly quantitative problems make any effort either to eliminate or determine the magnitude of this source of error in his case and in a specific instance? Anyone who has not experimented for himself on the matter can hardly realize how important, on the one hand, and how difficult on the other hand, it is to attain to any considerable degree of real objectivity in results. While the "exact" sciences are somewhat better off in this regard than biology, they are after all not greatly so. There has, to be sure, been a great deal of work done

[1] Bateson, W., "Mendel's Principles of Heredity." 2d Edit., Cambridge, 1909.

[2] East, E. M., and Hayes, H. K., "Inheritance in Maize." Conn. Agr. Expt. Stat., Bulletin 167, 1911.

[3] Yule, G. U., "On the Influence of Bias and Personal Equation in Statistics of Ill-defined Qualities." *Jour. Anthropol. Inst.*, Vol. XXXVI., pp. 325–381, 1906.

on the theory of errors of observation, particularly as related to astronomy, physics, and like subjects, yet so late as 1902 Pearson[1] demonstrated in a most convincing manner that much of the then currently accepted theory was wrong, and that all of it quite overlooked a factor which might be exceedingly important, namely, correlation of judgments.

The present study is by no means a complete investigation of the problem of personal equation in Mendelian work. Correlation of errors ought to be studied, and certain other matters as well. But the present material is statistically entirely inadequate for the discussion of these points, and it does not seem feasible to collect more extensive data, since to do so involves too great a trespass on the time and good nature of busy workers. Further the material here presented brings out clearly the primarily essential points. It shows that in a Mendelian ratio the personal equation of the observer marks a source of error which in the case of maize is of considerable magnitude. This source of error quite overshadows in magnitude, in this case, the error due to random sampling. Yet it is the latter alone which is ordinarily considered by Mendelian workers. The probable error of a Mendelian ratio as commonly calculated tells one the probability that the sample counted is a true representation of the general population from which it was drawn. It tells one nothing whatever about the unconscious bias of the counter as a factor in producing the result set down.

By way of summary it may be said that in this paper evidence is presented which shows that:

1. The observed F_2 Mendelian ratios determined from the same four ears of maize by fifteen competent observers all differ from one another.

2. The failure of all observers to agree in their distribution of kernels into several categories results from two causes, viz., (*a*) the existence of somatically intermediate kernels, and (*b*) the personal bias or idiosyncracy of the observer.

3. The magnitude of the differences between the several observers is such as to demonstrate that the personal equation

[1] Pearson K., "On the Mathematical Theory of Errors of Judgment, with Special Reference to the Personal Equation." *Phil. Trans. Roy. Soc.*, A, Vol. 198, pp. 235–299, 1902.

is a factor which cannot safely be neglected in work of this character.

4. The observers who have had most experience in the appreciation and measurement of variation have the smallest personal equations on the class of material and the problem here treated.

5. There is no evidence that the progeny of somatically intermediate kernels is different, in any respect whatsoever, from the progeny of distinctly non-intermediate kernels of the same gametic constitution.